Finite element modelling of 1-3 piezoelectric polymer composites with surface effects

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As is known, the properties of nanobodies can significantly differ from similar properties of bodies of ordinary size. To describe this scale effect, a number of different theories and models of nanomechanics were developed. One of such widely used theories is the model of surface elasticity. In turn, among the theories of surface elasticity, the Gurtin-Murdoch model is now more popular. The use of this model leads to the fact that the boundaries of the nanoscale body are covered with elastic membranes, the internal forces in which are determined by surface stresses. Elastic membranes can be placed inside the body with nanoscale inclusions at the interphase boundaries, which also allows modelling imperfect interface boundaries with stress jumps.

The Gurtin-Murdoch model was also transferred to piezoelectric nanoscale bodies. According to this model, the surface constitutive relations were formulated, which are valid on the boundary of the piezoelectric body, and the terms with surface nabla-operators from surface stresses and surface electrical induction were added to the mechanical and electrical boundary conditions. Similarly, on the nanoscale interphase boundaries inside the body, it is also possible to specify surface constitutive relations and interface boundary conditions with surface values. For statements of dynamic problems, taking into account damping effects, the dynamic surface or interface equations can be supplemented by surface damping terms. All of these models reflect dimensional effects and affect on the overall electromechanical state, if the inclusions are only nanoscale.

The described models were used both for the formulation of initial-boundary and boundary-value problems for 1-3 polymer piezoelectric nanostructured composites, and for solving the problems of determining their effective properties. For the numerical solution of these problems, finite element technologies and the ANSYS software package were used. In the simulation, one composite cell with a nanoscale piezoelectric rod in a polymer matrix was considered. The ends of the rod were supposed to be covered with electrodes. Surface effects were set both on the interface lateral surface of the contact between the rod and the polymer matrix, and on the end faces. Finite element modelling of surface effects was carried out by means of shell elements with options of membrane stresses and by using special volume elements with coupled degrees of freedom.

Finite element solutions of static problems, modal problems and problems of steady-state oscillations for various values of surface moduli were obtained. For modal problems, the first frequencies of electric resonances and antiresonances were determined and the dynamic coefficients of the electromechanical coupling were calculated. For a rod with a circular cross section, the approximate analytical solutions were also obtained and these solutions were compared with corresponding numerical solutions. The analysis showed a significant effect of surface moduli and nanoscale thickness on the basic characteristics of the composite structure in static and dynamic operating modes.

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